УДК 621.564

O. Ostapenko ✉**, *O. Yakovleva, M. Khmelniuk***
Odessa National Academy of Food Technologies, 112 Kanatnaja str., Odessa, 65039, Ukraine
✉ e-mail: ORCID:

OPTIMAL PROCESS SYSNTHESIS FOR REFRIGERATION SYSTEM OF ASSOCIATED GAS LOW-TEMPERATURE CONDENSATION PLANT

Design of modern high-efficient systems is a key priority for the Energy Sector of Ukraine. The object of the present study are the cooling process streams of gas and oil refineries, including air coolers, water cooling and refrigeration systems for specific refrigerants. Improvement of the refrigeration unit unit with refrigerant separation into fractions is mandatory in order to increase cooling capacity, lowering the boiling point of coolant and increasing the coefficient of target hydrocarbons extraction from the flow of associated gas. In this paper it is shown that cooling temperature plays significant role in low-temperature condensation process. Two operation modes for refrigeration unit were proposed: permanent, in which the concentration of the refrigerant mixture does not change and dynamic, in which the concentration of refrigerant mixtures depends on the ambient temperature. Based on the analysis of exergy losses the optimal concentration of refrigerant mixtures propane/ethane for both modes of operation of the refrigeration unit has been determined. On the basis of the conducted pinch-analysis developed the modification of refrigeration unit with refrigerant separation into fractions. Additional recuperative heat exchangers for utilization heat were added to the scheme. Several important measures to increase the mass flow rate of refrigerant through the second section of the refrigeration centrifugal compressor from 22.5 to 25 kg/s without violating the agreed operational mode of the compressor sections were implemented.

Key words: *propane/ethane; refrigerant mixture; exergy losses; centrifugal compressor; refrigerant concentration; refrigerant fractionation; pinch analysis; low-temperature condensation.*

А.В. Остапенко, О.Ю. Яковлєва, М.Г. Хмельнюк
Одеська національна академія харчових технологій, вул. Канатна, 112, Одеса, 65039, Україна

ОПТИМАЛЬНИЙ СИНТЕЗ ПРОЦЕСІВ ДЛЯ ХОЛОДИЛЬНОЇ СИСТЕМИ КОМПЛЕКСУ НИЗЬКОТЕМПЕРАТУРНОЇ КОНДЕНСАЦІЇ ПОПУТНОГО НАФТОВОГО ГАЗУ

Створення сучасних високоефективних систем є ключовим пріоритетом для енергетичного сектору України. Метою проведеного дослідження є охолоджуючі технологічні потоки газових і нафтових підприємств, у тому числі апарати повітряного охолодження, системи охолодження води та холодильні системи для конкретних холодоагентів. Схема холодильної установки з розділенням холодоагенту на фракції була модифікована для того, щоб збільшити охолоджуючу здатність, знизити температуру кипіння холодоагенту і підвищити коефіцієнт вилучення цільових вуглеводнів від потоку попутного газу. Показано, що температура охолодження попутного нафтового газу відіграє важливу роль у процесі низькотемпературної конденсації. Було запропоновано два режими роботи для холодильної системи: постійний, при якому концентрація суміші холодоагенту не змінюється, і динамічний, при якому концентрація суміші холодоагенту залежить від температури навколишнього середовища. На основі аналізу втрат ексергії була визначена оптимальна концентрація суміші холодоагенту пропан / етан для обох режимів роботи холодильної системи. На підставі проведеного пінч-аналізу була модифікована холодильна установка з розділенням холодоагенту на фракції. У схему були додані додаткові рекуперативні теплообмінники для утилізації теплоти. Реалізовані заходи щодо збільшення масової витрати холодоагенту через другу секцію відцентрового холодильного компресора від 22,5 до 25 кг/с, не порушуючи узгоджений режим роботи секцій компресора.

Ключові слова*: пропан/етан; суміш холодоагенту; втрати ексергії; відцентровий компресор; концентрація холодоагенту; фракціонування холодоагенту; пінч-аналіз; низькотемпературна конденсація.*

DOI:

I. INTRODUCTION

According to the Energy Strategy of Ukraine for the period until 2035 the creation of high-energy systems and rational use of energy resources in energy-intensive industries are the priority areas of the Ukrainian energy sector for economy. The problem solving requires improving the energy sector of existing gas processing enterprises (GPE), which is a multi-level technical system of interconnected by flows of energy resources within the internal industrial power generating system of various types and purposes as well as production units, consuming one and generating other types of energy.

The object of the present study are the cooling process streams of gas and oil refineries, including air and water coolers, refrigeration systems for specific refrigerant mixtures. Companies, such as: Ortloff, IPSI, Bechtel, research facility of "Gazprom", VNIIGAZ, working with case study of improving the efficiency of existing gas processing plants, as well as the improvement of gas feedstock recycling processes. The majority of this companies offer a wide range of technologies and modifications aimed at increase of the extraction degree of hydrocarbons, energy-efficient technology, the use of waste energy in industrial processes, or use of environment potential as well as many others energy saving technologies.

It worth be mentioned that there are studies aimed at improving the efficiency of technological systems of the first and second generation gas processing plants. Research companies provide different retrofit opportunities of existing processes. Some studies is focused on improving the efficiency of the refrigeration systems: the modified ConocoPhillipsCascade process, for more efficient recovery of propane (IPSI), Supplemental Rectification Process, (Ortloff), Gas Subcooling Process, (Ortloff) and others.

II. LOW-TEMPERATURE CONDENSATION REFRIGERATION UNIT

Cold production in the LTC (Low-Temperature Condensation) units requires significant amount of energy resources. This state of affairs forces the various organizations and enterprises, which are using low temperature processes, to find energy efficient solutions for their business applications.

One way for improving efficiency is to reduce energy losses, improving the cooling processes of the APG (Associated Petroleum Gas) recovery, improving efficiency of the existing equipment. Cooling the natural gas stream to a lower temperature in low-temperature condensation units improves the efficiency of the APG recovery, by increasing the amount of recoverable hydrocarbons and reducing gas flared.

Higher efficiency of the existing installation can be reached in several ways: reduction of energy losses, improvement of the cooling, supplied to the APG, retrofit of the existing equipment and use of the environment potential.

Refrigeration unit of the low-temperature condensation complex works on R290 as a working fluid. Reducing the propane temperature below the boiling point $t_0 = -38$ °C cannot be done due to an invalid operation of centrifugal compressor. Adding a certain amount of the hydrocarbons with lower boiling point to the propane-refrigerant, such as R170 (ethane) let us to get a lower boiling point while maintaining boiling pressure at the required level.

Quality indicator of hydrocarbon extraction process from APG flow is the extraction ratio, which reaches values of 88-90%. Analysis of monitoring data of the LTC unit shows the general trend that reflects a stable dependence of the number of products derivable from the temperature level of a number of processes, in LTC installation an important role plays initial temperature of the gas flow and corresponding condensate obtained (Fig. 1). Lowering the temperature of the gas flow can increase the recovery and increase the amount of condensed hydrocarbons.

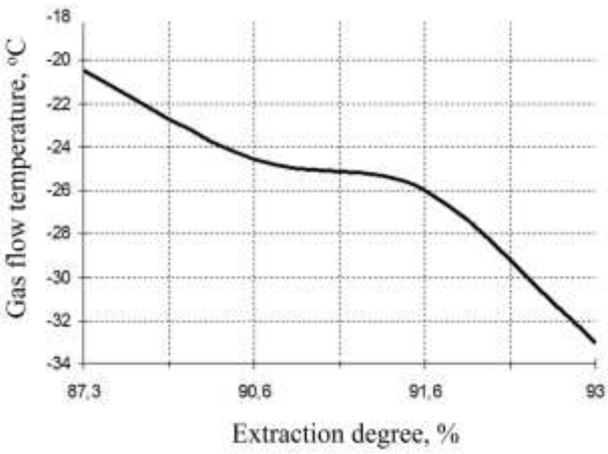

Figure 1 *− Extraction ratio of target hydrocarbons*

Among the various techniques used to optimize energy consumption in the manufacturing industry, pinch-analysis method is known as a powerful tool of thermodynamic analysis of chemical processes and related energy sources. The advantage of this method is the ability to determine the energy potential of installation. However, pinch analysis provides only the target heat load of heat exchanger via the mass and energy balance of the basic processes such as refrigeration cycles and gas/steam turbine cycles. On the other hand exergy analysis is a very effective method for measuring the performance or power consumption of the shaft. Thus, the correct combination of the exergy analysis and the pinch analysis may be a valuable and practical solution for the simultaneous measurement of both heat and shaft work in such systems. This method is also known as the combined pinch and exergy analysis. Developments in heat exchange networks optimization reached the highest peak, when it was suggested that the determination of the heat recovery by using of the pinch-analysis technology.

III. REFRIGERATION UNIT PERFORMANCE INDICATORS

For cold production in low-temperature condensation installation the propane refrigeration unit (PRU) is used (Fig. 2). PRU is equipped with centrifugal propane refrigeration compressor TP5-5, four-staged, double-sectioned. Each section consists of two compression stages and sections themselves are consistent. Refrigeration system (Fig. 2) uses as the working fluid a mixture of hydrocarbons propane/ethane (R290/R170). Previous studies indicate that there are multiple options for working fluid usage in PRU such as: propane/ethane and propane/ethane/isobutane (R290/R170/R600a).

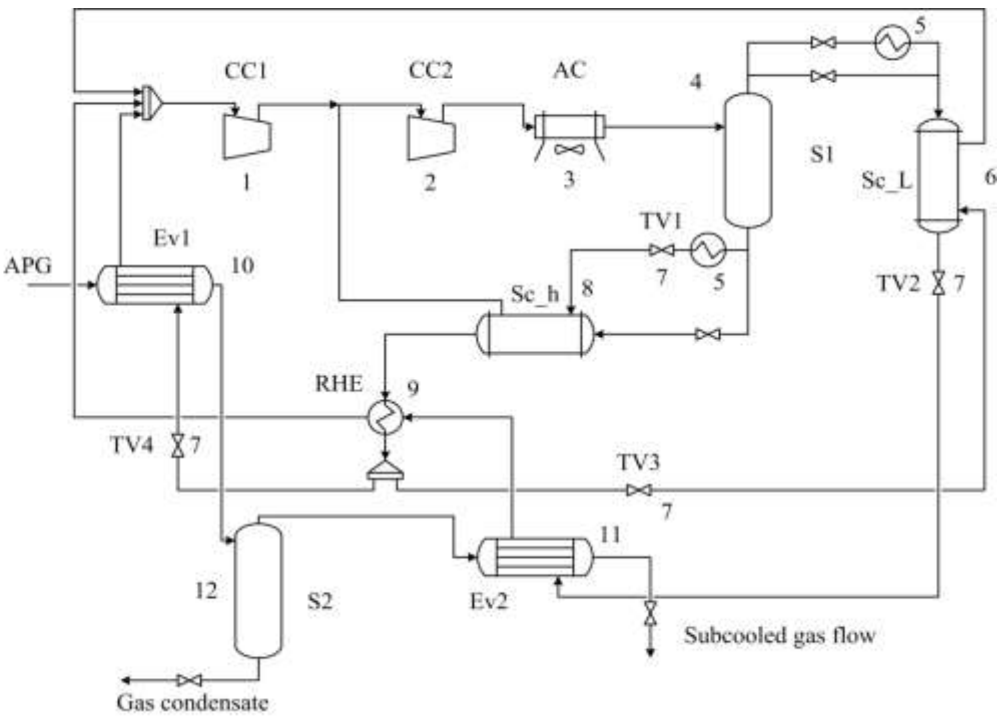

Figure 2 *− Simplified diagram of the refrigeration unit with refrigerant fractionation.*
1 - the first compressor section 2 - the second compressor section 3 - air cooler, 4 - separator, 5 – refrigerant fractions condensing units, 6 – low-temperature refrigerant subcooler, 7 – throttling valve, 8 - high boiling temperature refrigerant suncooler, 9 - regenerative heat exchanger, 10 - high-temperature refrigerant evaporator, 11 - a low-temperature refrigerant evaporator, 12 - gas condensate separator.

Use of different refrigerant’s weight ratios has been considered. The following concentrations were suggested: 80/20, 85/15, 90/10, 95/15 wt. %. Concentration of propane/ethane of 85/15 wt. % allows to achieve 2,24MW cooling capacity from the high-boiling temperature refrigerant (refrigerant fraction enriched with propane after separator, *4*) at boiling temperature -42.5 °C and 1,794MW of cooling from the low-boiling temperature refrigerant (refrigerant fraction with high content of ethane) at boiling temperature -49.5 °C. Total cooling capacity of current design is 4MW at an ambient temperature of 30 ° C. If the ambient temperature is below or equal to 6 ° C, the low-boiling temperature refrigerant can be fully condensed by cooling of ambient air in the air coolers, *3* (at a pressure of 1.5 MPa, the condensing temperature is 16 °C).

In this case, the cooling capacity of PRU is increased to 5.9 MW. Cooling capacity of low-boiling temperature refrigerant fraction will remain the same – 1.794 MW, and for a high-boiling temperature refrigerant – will be increased by the amount of cold, previously required for the condensation of a cold-boiling refrigerant. In other words – the entire flow of supercooled high-boiling refrigerant will go to evaporator Ev1 *10*. According to figures 3 and 4 there is dependence of the cooling capacity and exergy efficiency of the plant on the concentration of refrigerant. Fig. 3 shows the trend in cooling capacity of PRU at conditions, based on the complete condensation of the refrigerant mixture.

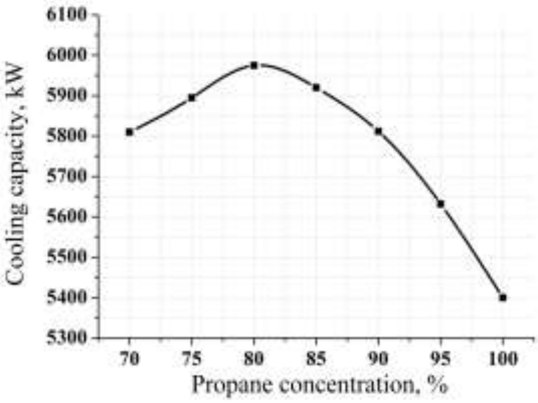

Figure 3 *— Useful cooling capacity of PRU with refrigerant fractionation.*

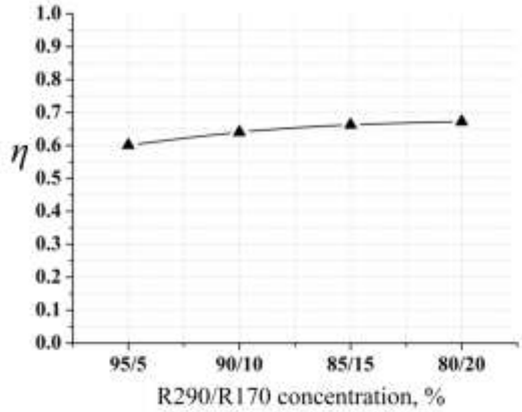

Figure 4 *— Exergy efficiency of PRU with refrigerant fractionation*

Addition of a low-boiling hydrocarbons such as ethane (R170) can reduce the boiling point of the refrigeration unit, as well as to increase the cooling capacity up to 10-11% (598 kW) from the nominal capacity of the system (5400 kW) on a pure propane working fluid (R290).

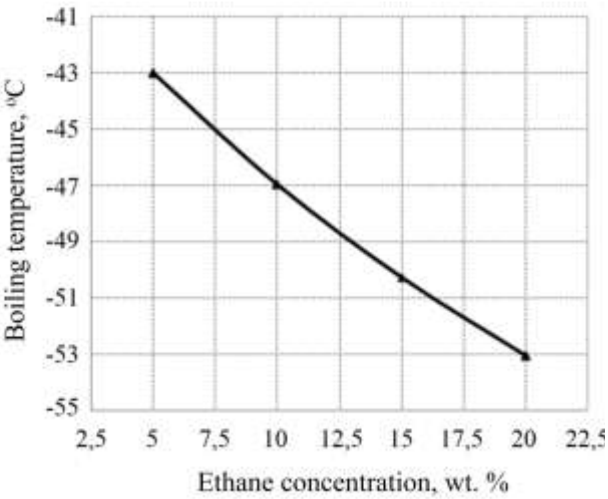

Figure 5 *— Average boiling temperature of refrigerant mixture at 1.2 bar pressure*

Presented in Fig. 5 graph shows that for the same pressure, with increasing concentrations of ethane, there is a decrease in the average boiling temperature of the mixture.

Nominal cooling capacity settings are different from those based on other selected temperature range.

Previous studies focused on the assessment of the compatibility of the centrifugal compressor and the use of propane/ethane hydrocarbon mixture as the working fluid. Experiment results confirmed the possibility of using non-zeotrope refrigerant with the maximum concentration of 18-20 wt. % due to the fact that the mixture has a high specific volume and at the same volumetric productivity of the centrifugal compressor, mass productivity decreases. Performance tests of centrifugal compressor were conducted at a frequency of 4400 rpm, 5700 rpm and 8800 rpm.

IV. ANALYSIS OF PROPANE REFRIGERATION UNIT

For the efficiency improvement of initial refrigeration unit design it is necessary to include additional heat exchangers to the system. The total amount of five heat exchangers was added to the refrigeration unit. Composite curves in T-H coordinates were constructed for a particular ambient temperature. Hot and cold composite curves are shown on Fig. 6.

In PRU with refrigerant fractionation (Fig. 2) heat transfer occurs between cold and hot flows of associated petroleum gas (APG), refrigerant flows and broad fraction of light hydrocarbons (BFLC) flows. Use of external utilities is minimized. As an external energy source the air in air coolers is used. On Fig. 7 Q_{Cmin}= 1687 kW is the value of cold utilities Q_{Hmin} = 201,67 kW – hot utilities and maximum value of heat utilization Q_{rec} = 5622 kW in the system at minimal working temperature difference ΔT_{min} = 5,2 K. Further displacement of curves (composite curve) is not appropriate, based on the fact that by increasing ΔT_{min} to 10 K maximum value of heat utilization is reduced to 5150 kW.

For further research the mixture of R290/R170 with concentration of 85/15 wt. % was chosen, hence this mixture of the refrigerant can supply highest cooling capacity – 5.98 MW, the exergy efficiency of the plant raises to a maximum value of 0.69, but the power consumption of the first and second sections of centrifugal compressor rises to 10% and 23%, respectively.

Energy, capital and total costs, are summarized on Fig. 7 depending on the ΔT_{min}. This graph allows to determine the minimum value of the total costs required to install additional heat exchangers at ΔT_{min} = 5.2 K.

Capital costs are:

$$C = N\left[a + b\left(\frac{A}{N}\right)^{c}\right] \quad (1)$$

where a, b and c – coefficients, which are depends on meterials, used by heat exchanger manufacturer, pressure ratio and heat exchanger type. Coefficient a

can be indentified with heat exchanger installation cost, coefficient *b* equals to 1 m^2 area cost, and coefficient *c* reflects non-linear dependence of heat exchanger cost from the heat exchange area.

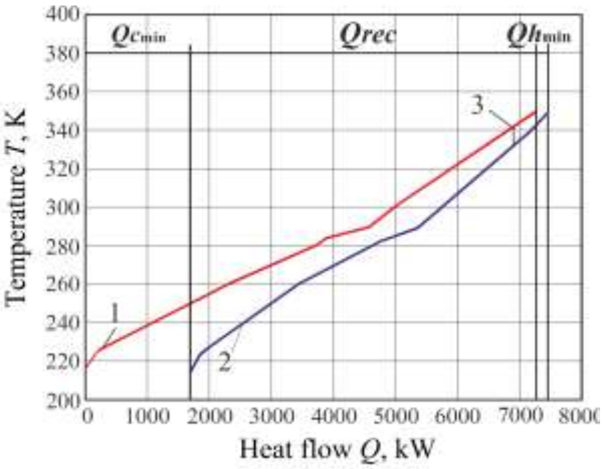

Figure 6 *– Composite curves of the PRU processes: 1– hot composite curve; 2 – cold composite curve; 3 – ΔT-pinch; Q_{Cmin} – cold utilities; Q_{Hmin} – hot utilities; Q_{rec} – amount of recuperated heat.*

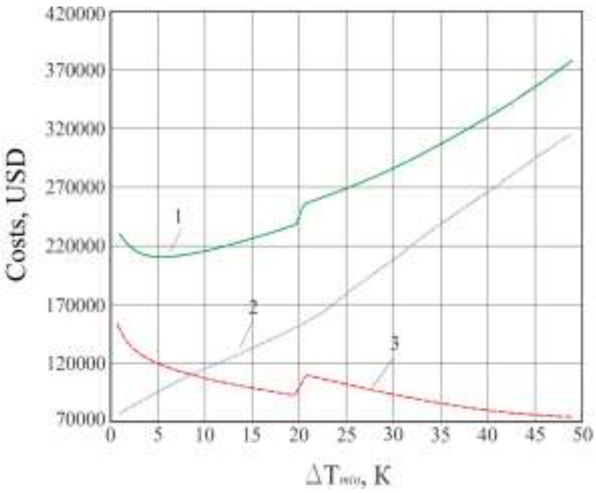

Figure 7 *– Costs at ΔT_{min}: 1 – total costs; 2 – capital costs; 3 – energy costs.*

Energy costs:

$$C_e = \frac{P_a \cdot P_o}{100} \cdot C \cdot \beta \cdot \Delta W \quad (2)$$

Total exergy losses in the systems:

$$\Delta D_e = \sum \Delta E_1 - \sum \Delta E_2 \quad (3)$$

Reduced power consumption:

$$\Delta W = \frac{1}{\eta_s} \Delta D_e \quad (4)$$

Minimal required area of heat exchangers to ensure heat recovery can be represented as:

$$A_{min} = \sum_i^{interval} \frac{1}{\Delta T_{lm,i}} \left[\sum_j^{streams} \left(\frac{Q}{H} \right)_j \right]_i \quad (5)$$

V. REFRIGERATION UNIT OPTIMISATION

Use of pinch analysis allowed to debottleneck the initial PRU design and to increase its cooling capacity. The modified scheme of PRU includes additional recuperative heat exchangers for heat utilization.

Developed and implemented measures for increasing mass flow rate of refrigerant through the second section of the centrifugal compressor from 22.5 to 25 kg/s while maintaining the agreed mode of both sections of the compressor. Cooling capacity of the high-boiling temperature evaporator increases by 543.4 kW compared with the initial PRU design (Fig. 2), but the cooling capacity of the low-boiling temperature evaporator was reduced by 16 kW.

New installation design is shown in Fig. 8. It provides a more efficient operation for the refrigeration unit with the working fluid R290/R170 fractionation. Key principles remain unchanged, i.e., refrigerant flow separation is carried out after the AC *3* in the separator *4*, the flow of low-boiling refrigerant is condensed by evaporation of high-boiling temperature refrigerant flow, after which receives a RHE and throttled through TV3 to the boiling pressure of 0,12 MPa.

Refrigeration system design with refrigerant fractionation (see fig. 2) supplemented with the additional recuperative heat exchangers HE-1, HE-2, HE-3, and the intercoolers IC1 and IC2. Intercooler IC1 *9* cools the refrigerant flow from the subcooler HBSC *7* before suction into the second centrifugal compressor section *2*. The gas cooler IC2 is added in order to increase the cooling capacity and the amount of natural gas liquids produced in the separator S2 *13* by cooling of vaporized low-boiling temperature refrigerant which is going to suction to first stage of centrifugal compressor section CC1 *1*. High-boiling temperature refrigerant flow before entering the recuperative heat exchanger RHE *15* is added to the separator, whereby a portion of the refrigerant stream is cooled in a series of recuperative heat exchangers, HE-3 *17* and HE-1 *11*, thereby achieving a lower temperature before the RHE *15* and reducing the amount of the vapor phase after throttling in TV3 and TV4.

Addition of the intercooler IC1 (Fig. 9, 10) with heat load of 300 kW and increased heat load of high-boiling temperature subcooler *7* from 792.5 to 1247.2 kW may save agreed operation mode of the compressor sections with simultaneously solving the problem of improving the efficiency of the refrigeration unit.

Installation of additional regenerative heat exchanger for heat utilization makes it possible to get additional cooling capacity in the amount of 209.5 kW at temperature level -45 °C and cool APG stream, getting more liquid phase, which is given in the separator S2 and consequently increase the efficiency of the compressor.

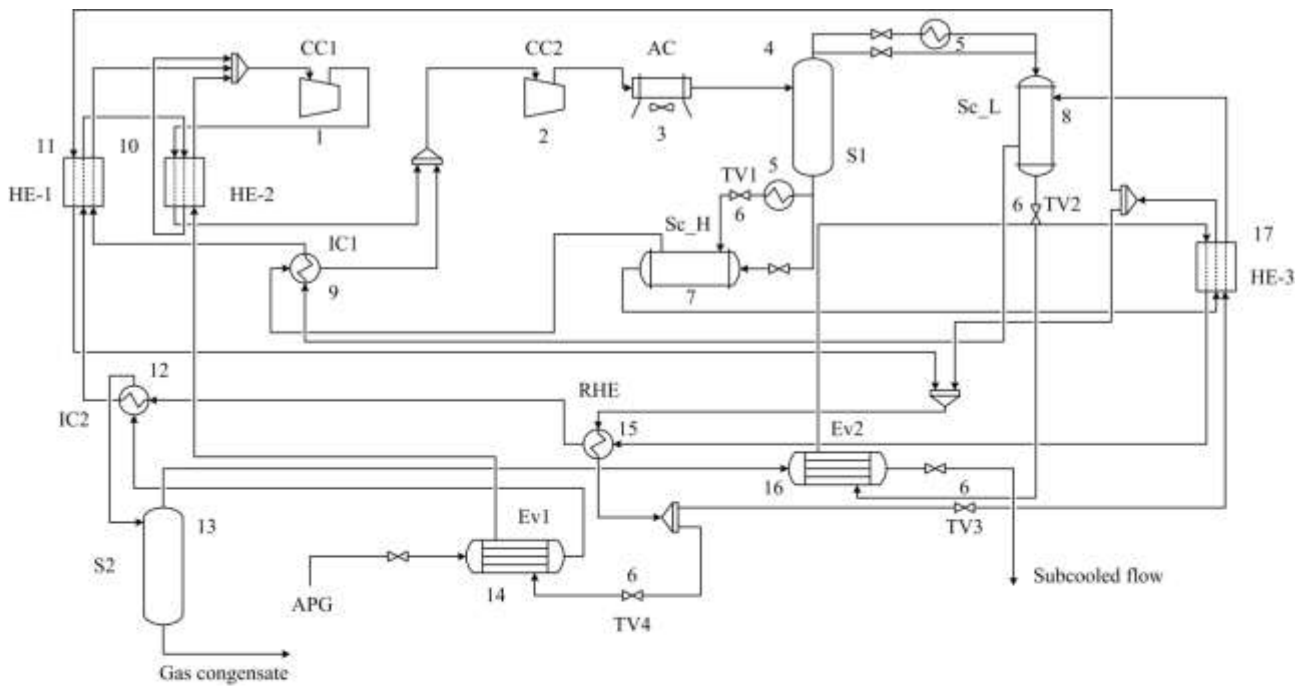

Figure 8 *– Modified design of the refrigeration unit with refrigerant fractionation.*
1 - the first compressor section 2 - the second compressor section 3 - air cooler, 4 - separator, 5 – refrigerant fractions condensing units, 6 – throttling valves, 7 – high-boiling temperature refrigerant subcooler, 8 – low-temperature refrigerant subcooler, 9, 12 – intermediate subcoolers, 10, 11, 15, 17 – recuperative heat exchangers, 13 – intermediate gas condensate separator, 14 – low-boiling temperature refrigerant evaporator, 16 – high-boiling temperature refrigerant evaporator.

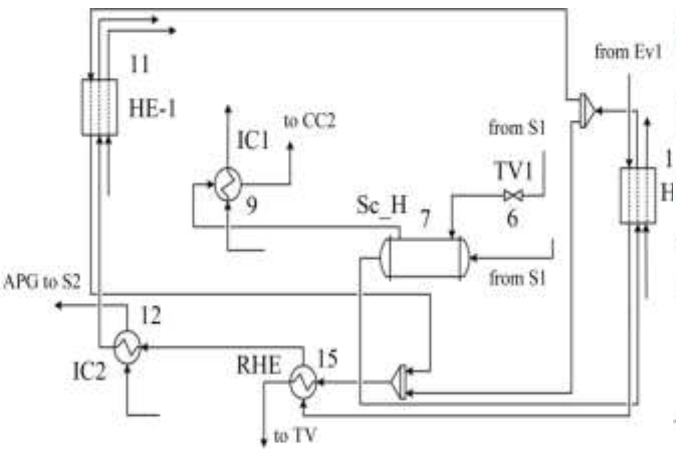

Figure 9 *– Design fragment with subcoolers and RHE.*
6 – throttling valve, 7 – high-boiling temperature refrigerant subcooler, 9, 12 – intermediate subcoolers, 11, 15, 17 – recuperative heat exchangers.

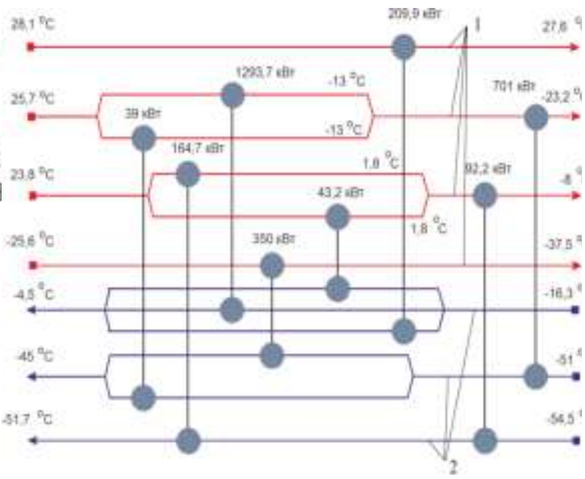

Figure 10 *– Heat exchange network of the Scheme fragment with subcoolers and RHE.*
1 – hot streams, 2 – cold streams

A comparison of the differend design options for PRU were made. Exergy efficiency and cold production costs were calculated.

Exergy efficiency of refrigeration unit:

$$\eta_e = \frac{Q_{e1}+Q_{e2}}{W_1+W_2} \quad (6)$$

Exergy cooling capacity

$$Q_{e1} = Q_o \cdot \tau_e \quad (7)$$

Exergy temperature function:

$$\tau_e = \frac{T_a}{T_o} - 1 \quad (8)$$

Consumed power for cold production on each temperature level:

$$N_e = \frac{Q_o}{\eta_{el}}\left(\frac{T_h - T_c}{T_c}\right) \quad (8)$$

Electricity costs for cold production:

$$C_e = N_e \cdot c_e \cdot h \quad (10)$$

Table 1 – Comparison of the differend design options for PRU.

	PRU with refrigerant fractionation		**Modified PRU design with refrigerant fractionation**	
Refrigerant concentration, %	80/20	85/15	80/20	85/15
Power consumption, kW:				
1-st section of centrifugal compressor	1463	1432	1516	1467
2-d section of centrifugal compressor	2210	2176	2781	2851
Cooling capacity, kW:				
Q_{o1}	1597	1406	1614	1250
Q_{o2}	3748	3705	4605	4306
Q_{o3}			284,5	571,5
Boiling temperature, ^oC				
t_{o1}	-49,75	-47,5	-51	-49
t_{o2}	-42	-41,5	-42,5	-41,5
t_{o3}			-45	-45
Exergetic efficiency	0,474	0,45	0,53	0,46
Hydrocarbons extraction degree	< 92%		< 95%	
Electricity costs for cold production, USD/year				
t_{o1}	404096	330792	414568	295624
t_{o2}	673624	782040	1107120	970144
t_{o3}			60368	117824

As indicated in Table 1 we can see data comparison of the refrigeration system using the proposed circuit design. Application of non-zeotrope mixture of refrigerant R290/R170 in propane refrigeration centrifugal compressor results in increased power consumption and consequently the produced cooling capacity increases to 23.2% compared to the non-modified design. At the same time, the addition of ethane in propane reduces the boiling point of the refrigerant to -51 ^oC, which is 13 degrees lower than the base propane refrigeration unit and cooling capacity. Reducing the temperature level will increase the degree of extraction of hydrocarbons from 88-90% to 95% compared to the non-modified design.

VI. CONCLUSIONS

Propane refrigeration unit design with refrigeration fractionation have been analyzed and optimized.

Operation modes of centrifugal compressor in the low-temperature condensation refrigeration plant were considered. The synthesis of the properly chosen refrigerant's concentration modified plant design and centrifugal compressor characteristics allows increasing cooling capacity up to 23.2%. The results of the study are especially valuable for the development of the advanced solutions for refrigerant mixture fractionation, which may lower the boiling point of refrigerant from -38 °C to -51 °C. Modified refrigeration unit design allows increasing the mass flow rate of the refrigerant from 22.5 to 25 kg/s and exergy efficiency from 0.474 to 0.53. Increasing the concentration of low-boiling temperature component will reduce condensation temperature. Refrigeration cycle with refrigerant flow fractionation and use of non-zeotrope working body will utilize the potential of the environment during the refrigeration unit operation.

NOMENCLATURE

$\boldsymbol{N}$	Number of added heat exchangers
$\boldsymbol{A}$	Total heat exchangers area (m^2)
$\boldsymbol{P}_a$	Charges for depreciation (6.4%)
$\boldsymbol{P}_o$	Charges for maintenance (2%)
$\boldsymbol{\beta}$	Cost of 1kW· $\boldsymbol{h}$ of electricity
$\Delta\boldsymbol{W}$	Total costs of electricity (USD)
$\boldsymbol{C_e}$	Energy costs (USD)
$\boldsymbol{C}$	Capital costs (USD)
$\Delta\boldsymbol{E_1}$	Exergy difference in the existing system
$\Delta\boldsymbol{E_2}$	Exergy difference of optimized system
$\boldsymbol{\eta_s}$	Adiabatic efficiency
$\boldsymbol{c_e}$	Costs of 1 kWh of electricity, USD
$\Delta\boldsymbol{T_{lm,i}}$	Logarithmic temperature difference
$\boldsymbol{Q_{e1}}, \boldsymbol{Q_{e2}}$	Exergy cooling capacities (kW)
$\boldsymbol{W_1}, \boldsymbol{W_2}$	Power consumption of sections (kW)
$\boldsymbol{Q_0}$	Cooling capacity (kW)
$\boldsymbol{\tau_e}$	Exergy temperature function
$\boldsymbol{N_e}$	Power consumption (kW)
$\boldsymbol{T_a}$	Absolute average ambient temperature (K)
$\boldsymbol{T_o}$	Absolute boiling temperature (K)
$\boldsymbol{T_h}$	Temperature of the cooling flow (K)
$\boldsymbol{T_c}$	Temperature of the hot flow (K)
$\boldsymbol{\eta_{el}}$	Electric motor efficiency
$\boldsymbol{h}$	Number of working hours

GPE	Gas Processing Enterprises	*CPEA*	Combined Pinch and Exergy Analysis
LTC	Low-Temperature Condensation	*PRU*	Propane Refrigeration Unit
APG	Associated Petroleum Gas	*BFLC*	Broad Fraction of Light Hydrocarbons

REFERENCES

1. **Lynch J.T., Wilkinson J.D., Hudson H.M., and Pitman R. N.** 2003, Process Retrofits Maximize the Value of Existing NGL and LPG Recovery Plants, Ortloff Engineers, Ltd. *82-nd convention of Gas Processors Association*, SA, Texas, 10 p.
2. **Le-Gall A., Laflotte B.** 2005, Compare the different options for NGL recovery from natural gas, Gas processing department, Technip, *Gastech*, 21 p.
3. **Kemp I. C.** 2007, *Pinch analysis and process integration* IChemE, UK, 396 p.
4. **Feng X., Zhu XX.** 1995, Combining pinch and exergy analysis for process modifications *Applied Thermal Engineering.* 17(1): P.250-260.
5. **Khmelniuk M., Ostapenko A., Yakovleva O.**, 2013. Low-temperature condensation refrigeration unit energy efficiency after applying of a hydrocarbon mixture as a working fluid in a propane refrigeration installation. "Compressors 2013", Papiernicka. 6 p.
6. **Ataei A. Chang K.Y.** 2010, Combined pinch and exergy analysis for energy efficiency optimization in a steam power plant *International Journal of the Physical Sciences.* 5(7), 1110-1123 p.
7. **Ostapenko O., Yakovleva O., Khmelniuk M.** 2013 Improvement of the refrigeration installation of the associated petroleum gas low-temperature condensation complex, *Journal of Industrial Gases,* 6 (2013), 23-28 p.
8. **Martynyuk M.O., Khmelniuk M.G.** 2009 Analysis of characteristics of propane refrigerating compressor such as type «TP5-5» at its work on a mixture propane/ethane *Journal of Industrial Gases* No 4. 23-28 p.
9. **Kwak HY.** 2003, Exergic and thermoeconomic analysis of power plant *Energy*, No 28, 343-360 p.
10. Smith R. 2005, *Chemical Process Design and Integration,* John Wiley & Sons Ltd, UK 714 p.

Received 15 May 2015
Approved 03 July 2015
Available in Internet 30.08.2015

А.В. Остапенко, О.Ю. Яковлева, М.Г. Хмельнюк
Одесская национальная академия пищевых технологий, ул. Дворянская, 1/3, г. Одесса, 65026

ОПТИМАЛЬНЫЙ СИНТЕЗ ПРОЦЕССОВ ДЛЯ ХОЛОДИЛЬНОЙ СИСТЕМЫ КОМПЛЕКСА НИЗКОТЕМПЕРАТУРНОЙ КОНДЕНСАЦИИ ПОПУТНОГО НЕФТЯНОГО ГАЗА

Создание современных высокоэффективных систем является ключевым приоритетом для Программы энергетической стратегии Украины на период до 2030 года. Целью проводимого исследования являются охлаждающие технологические потоки газовых и нефтяных предприятий, в том числе аппараты воздушного охлаждения, системы охлаждения воды и холодильные системы для конкретных хладагентов. Схема холодильной установки с разделением хладагента на фракции была модифицирована для того, чтобы увеличить охлаждающую способность, снизить температуру кипения хладагента и повысить коэффициент извлечения целевых углеводородов от потока попутного газа. Показано, что температура охлаждения попутного нефтяного газа играет важную роль в процессе низкотемпературной конденсации. Было предложено два режима работы для холодильной системы: постоянный, при котором концентрация смеси хладагента не изменяется, и динамичный, при котором концентрация смеси хладагента зависит от температуры окружающей среды. На основе анализа потерь эксергии была определена оптимальная концентрация смеси хладагента пропан/этан для обоих режимов работы холодильной системы. На основании проведенного пинч-анализа была модифицирована холодильная установка с разделением хладагента на фракции. В схему были добавлены дополнительные рекуперативные теплообменники для утилизации теплоты. Реализованы меры по увеличению массового расхода хладагента через вторую секцию центробежного холодильного компрессора от 22,5 до 25 кг/с, не нарушая согласованный режим работы секций компрессора.

Ключевые слова: *пропан/этан; смесь хладагента; потери эксергии; центробежный компрессор; концентрация хладагента; фракционирование хладагента; пинч-анализ; низкотемпературная конденсация.*